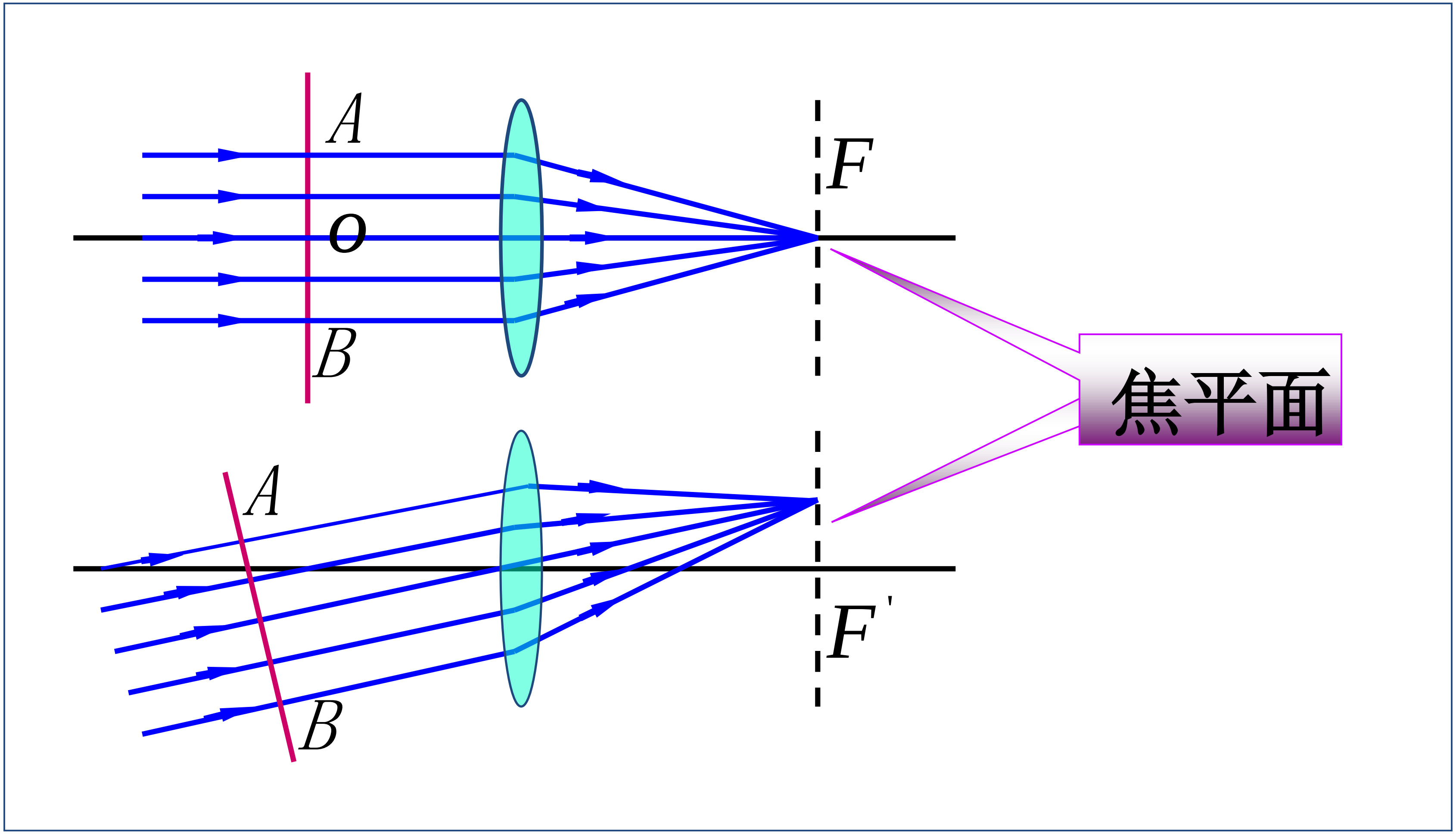
一 透镜不引起附加的光程差

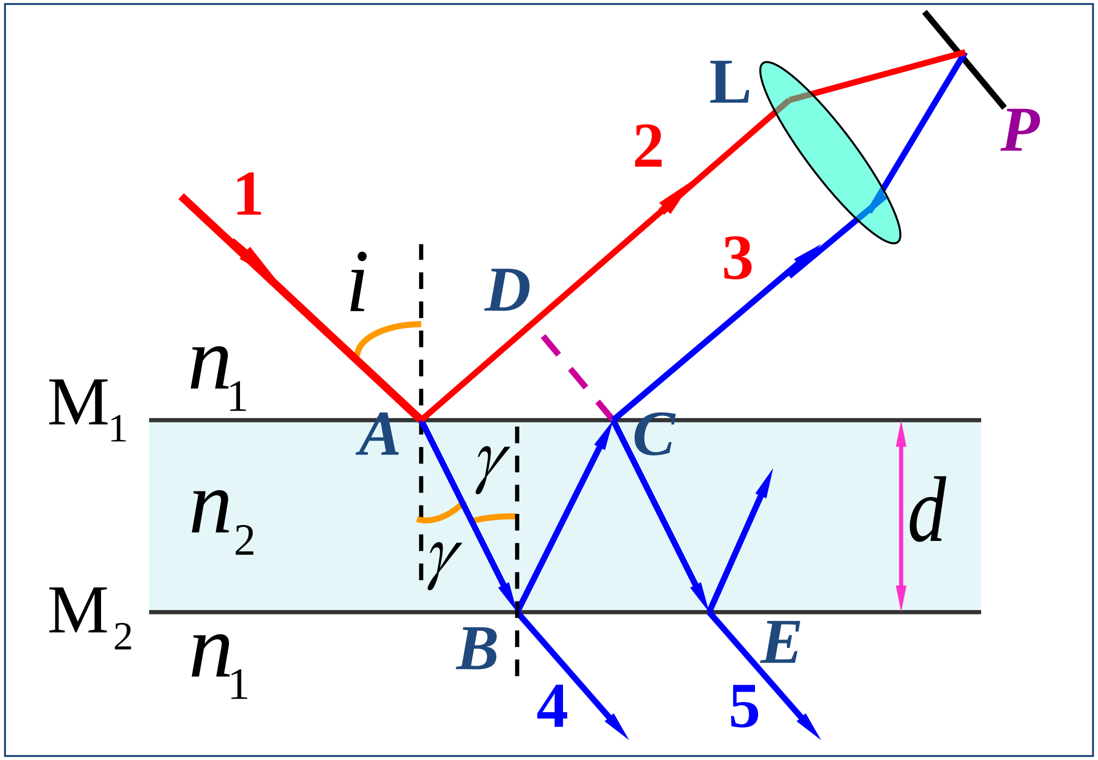


二　薄膜干涉的光程差

$$n_2 > n_1$$

$$CD \perp AD$$

$$\frac{\sin i}{\sin \gamma} = \frac{n_2}{n_1}$$

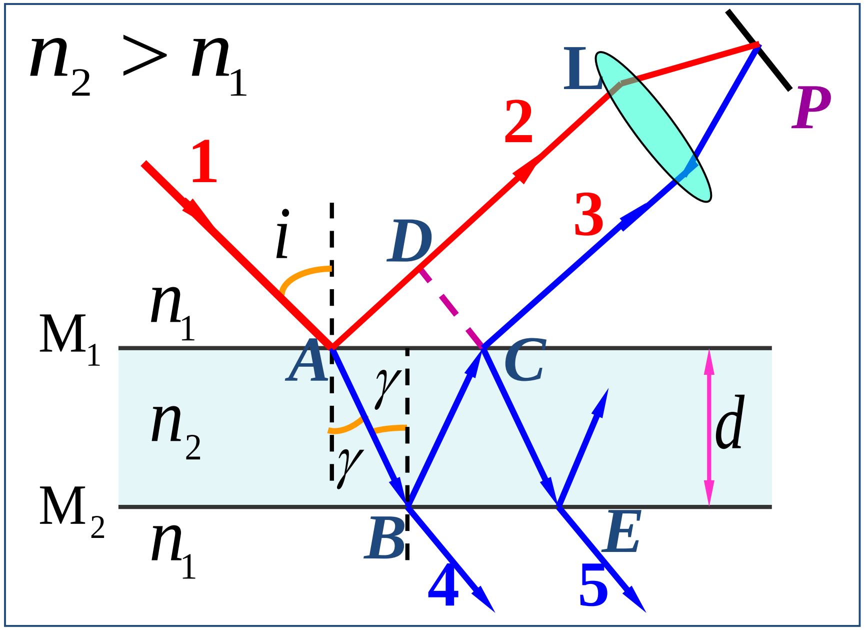


$$\Delta_{32} = n_2(AB + BC) - n_1 AD \boxed{+\frac{\lambda}{2}}$$

$$AB = BC = d/\cos\gamma$$

$$AD = AC\sin i$$

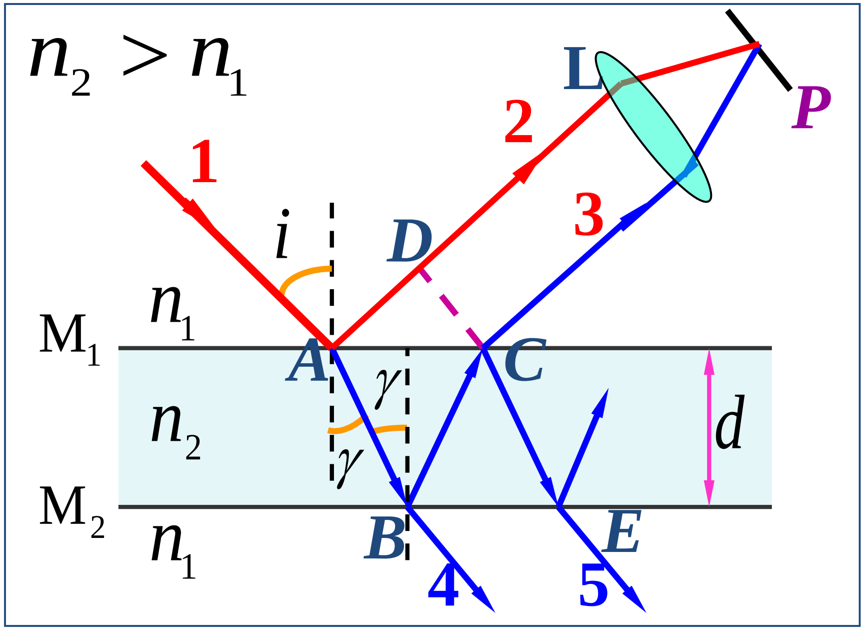
$$= 2d \cdot \tan\gamma \cdot \sin i$$



$$\Delta_{32}=\frac{2d}{\cos\gamma}n_2\left(1-\sin^2\gamma\right)+\frac{\lambda}{2}=2n_2d\cos\gamma+\frac{\lambda}{2}$$

- 反射光的光程差 $\Delta_{\mathrm{r}}=2d\sqrt{n_2^2-n_1^2\sin^2 i}+\dfrac{\lambda}{2}$

$$\Delta_{\mathrm{r}}=\begin{cases} k\lambda \quad (k=1,2,\cdots) & \text{加强} \\ (2k+1)\dfrac{\lambda}{2} \quad (k=0,1,2,\cdots) & \text{减弱} \end{cases}$$

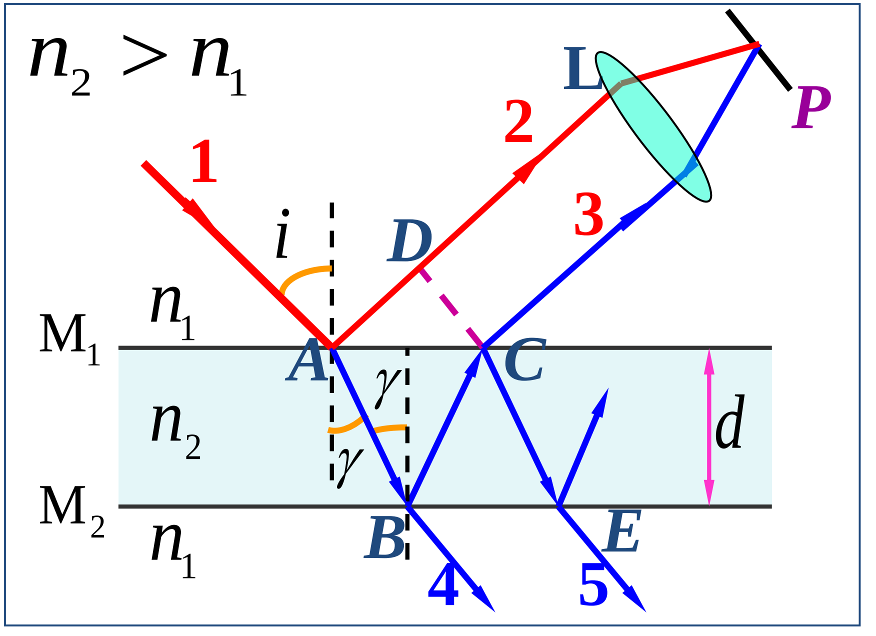


$$\varDelta_{\mathrm{r}} = 2d\sqrt{n_2^2 - n_1^2 \sin^2 i} + \boxed{\lambda/2}$$

根据具体情况而定

➢ 透射光的光程差 $\varDelta_{\mathrm{t}} = 2d\sqrt{n_2^2 - n_1^2 \sin^2 i}$

注意： 透射光和反射光干涉具有互补性，符合能量守恒定律.

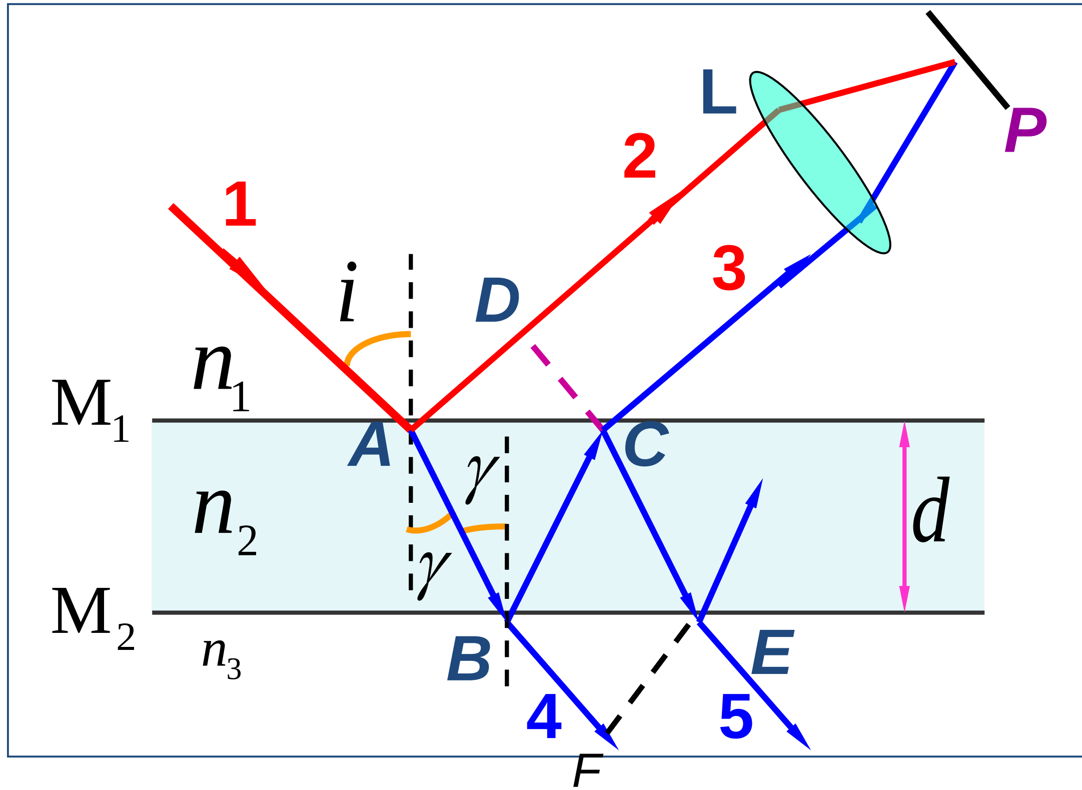


一般情况

n_1, n_2, n_3

$CD \perp AD$

$EF \perp BF$



$$n_1 \sin i = n_2 \sin \gamma = n_3 \sin i'$$

➢ 反射光的光程差

n_1, n_2, n_3

$$\Delta_{\mathrm{r}} = 2d\sqrt{n_2^2 - n_1^2 \sin^2 i} + \begin{cases} \lambda/2 & \text{无序排列} \\ 0 & \text{有序排列} \end{cases}$$

➢ 透射光的光程差

$$\Delta_{\mathrm{t}} = 2d\sqrt{n_2^2 - n_3^2 \sin^2 i'} + \begin{cases} 0 & \text{无序排列} \\ \lambda/2 & \text{有序排列} \end{cases}$$

$$n_1 \sin i = n_3 \sin i'$$

注意： 透射光和反射光干涉具有互补性，符合能量守恒定律.

讨论

$$\Delta_r = 2d\sqrt{n_2^2 - n_1^2 \sin^2 i} + \boxed{\frac{\lambda}{2}} = \begin{cases} k\lambda & k=1,2,\cdots \quad \text{明} \\ (2k+1)\dfrac{\lambda}{2} & k=0,1,2,\cdots \quad \text{暗} \end{cases}$$

若λ、n_1、n_2一定，Δ与d、i有关

(1) 薄膜厚度均匀(d一定)，Δ随入射角 i 变化

$$\left.\begin{array}{l}\text{同一入射角}i\text{ 对应同一级干涉条纹}\\ \text{不同入射角 对应不同级次的条纹}\\ \text{干涉条纹为一组同心圆环}\end{array}\right\}\text{等倾干涉}$$

(2) 入射角i一定(平行光入射)，Δ随薄膜厚度d变化

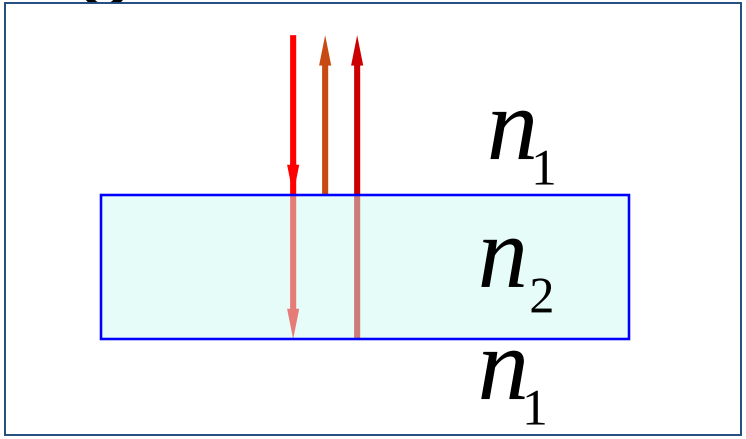
$$\left.\begin{array}{l}\text{薄膜同一厚度处对应同一级干涉条纹}\\ \text{薄膜不同厚度处对应不同级次干涉条纹}\\ \text{条纹形状与薄膜等厚线相同}\end{array}\right\}\text{等厚干涉}$$

均匀膜的等倾干涉

- 当光线垂直入射时 $i=0^\circ$

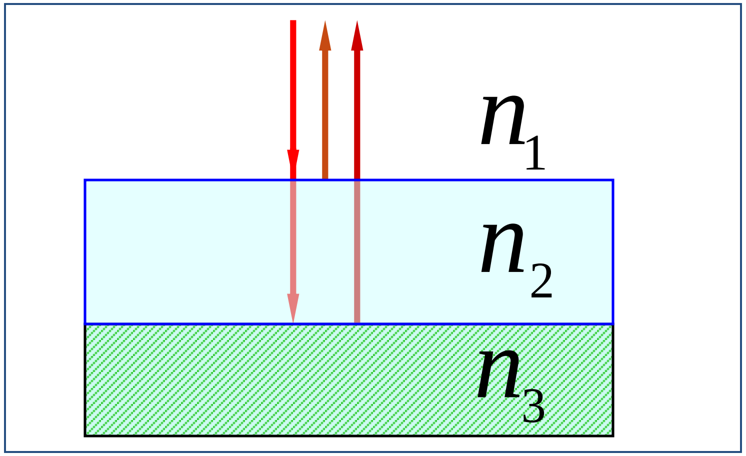
当 $n_2 > n_1$ 时

$$\Delta_r = 2dn_2 + \frac{\lambda}{2}$$



当 $n_3 > n_2 > n_1$ 时

$$\Delta_r = 2dn_2$$



例 1 一油轮漏出的油(折射率n_1=1.20)污染了某海域，在海水(n_2=1.30)表面形成一层薄薄的油污.

(1) 如果太阳正位于海域上空，一直升飞机的驾驶员从机上向正下方观察，他所正对的油层厚度为460 nm, 则他将观察到油层呈什么颜色?

(2) 如果一潜水员潜入该区域水下，并向正上方观察，又将看到油层呈什么颜色?

已知 n_1=1.20 n_2=1.30 d=460 nm

解 (1)$\Delta_{\mathrm{r}} = 2dn_1 = k\lambda$

$$\lambda = \frac{2n_1 d}{k}, \quad k = 1,2,\cdots$$

$$k = 1, \qquad \lambda = 2n_1 d = 1104\ \mathrm{nm}$$

$$k = 2, \qquad \lambda = n_1 d = 552\ \mathrm{nm}$$

绿色

$$k = 3, \qquad \lambda = \frac{2}{3} n_1 d = 368\ \mathrm{nm}$$

(2) 透射光的光程差 $\Delta_t = 2dn_1 + \lambda/2$

$$k = 1, \quad \lambda = \frac{2n_1 d}{1 - 1/2} = 2208\ \text{nm}$$

紫红色

$$k = 2, \quad \lambda = \frac{2n_1 d}{2 - 1/2} = 736\text{nm}$$ 红光

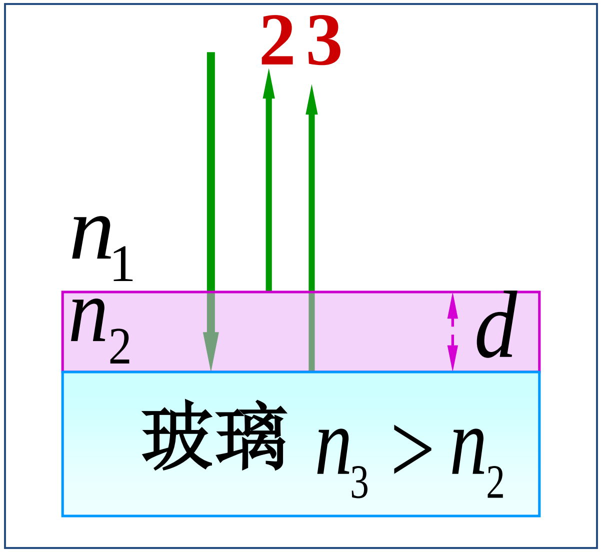
$$k = 3, \quad \lambda = \frac{2n_1 d}{3 - 1/2} = 441.6\text{nm}$$ 紫光

$$k = 4, \quad \lambda = \frac{2n_1 d}{4 - 1/2} = 315.4\ \text{nm}$$

◆ 增透膜和增反膜

利用薄膜干涉可以提高光学器件的透光率.

例2 为了增加透射率，求氟化镁膜的最小厚度．已知 空气n_1=1.00，氟化镁n_2=1.38，λ=550 nm



解 $\varDelta_{\mathrm{r}} = 2dn_2 = (2k+1)\dfrac{\lambda}{2}$

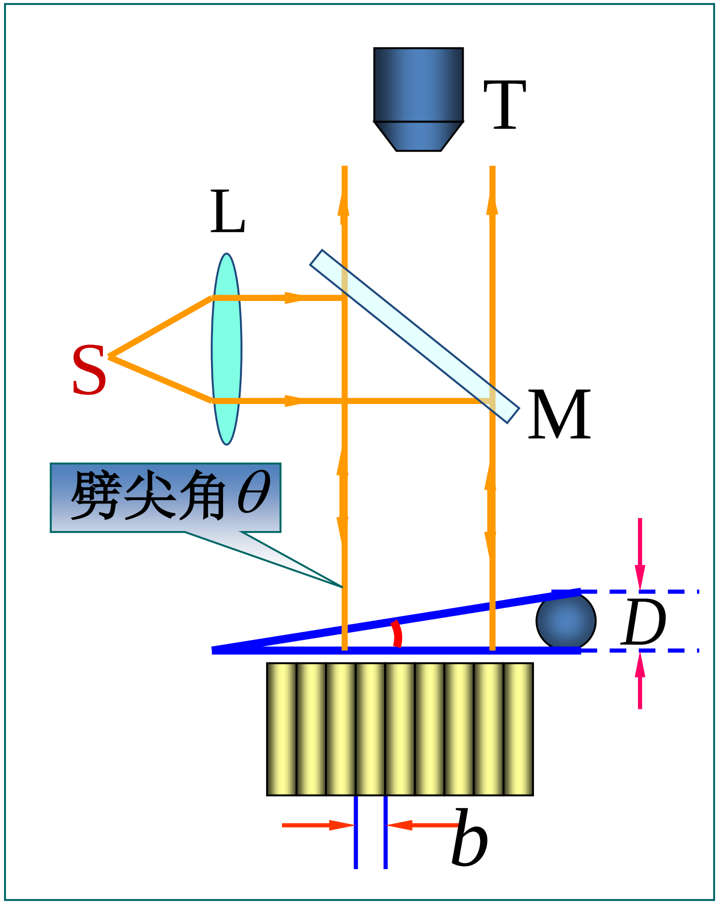
取 $k=0$ 减弱

$$d = d_{\min} = \frac{\lambda}{4n_2} = 99.6\,\mathrm{nm}$$

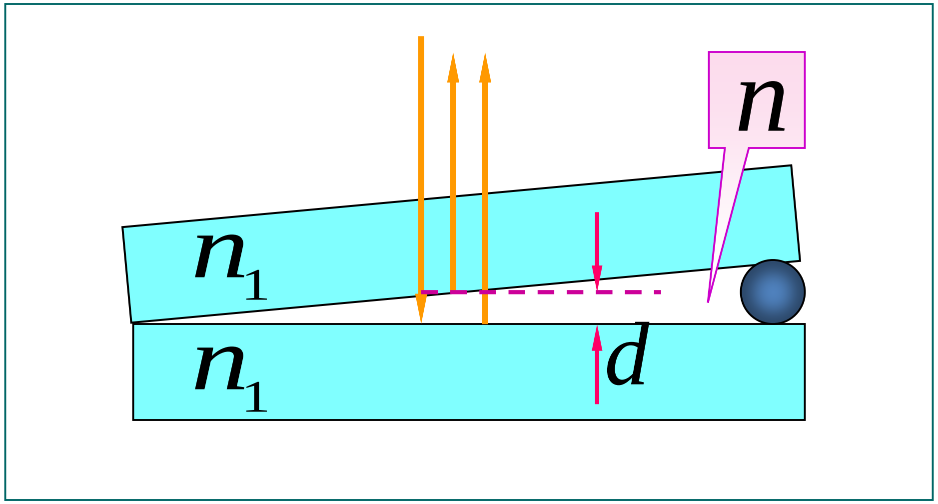
氟化镁为增透膜

则 $\varDelta_{\mathrm{t}} = 2n_2 d + \dfrac{\lambda}{2} = \lambda$ （增强）

一 劈尖

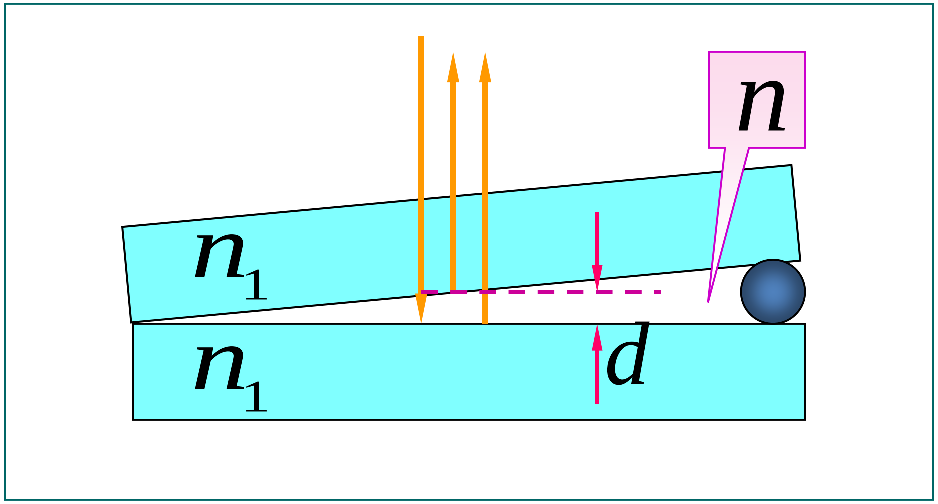


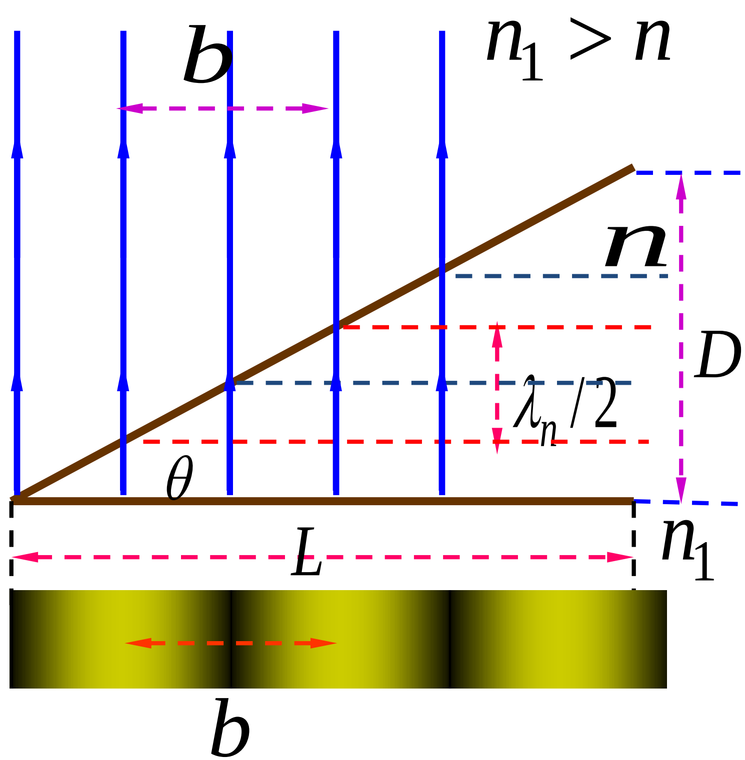
$$\varDelta = 2nd + \boxed{\frac{\lambda}{2}}$$



$$\Delta = 2nd \boxed{+\frac{\lambda}{2}}$$

$$\Delta = \begin{cases} k\lambda, \quad k = 1,2,\cdots & \text{明纹} \\ (2k+1)\dfrac{\lambda}{2}, \quad k = 0,1,\cdots & \text{暗纹} \end{cases}$$





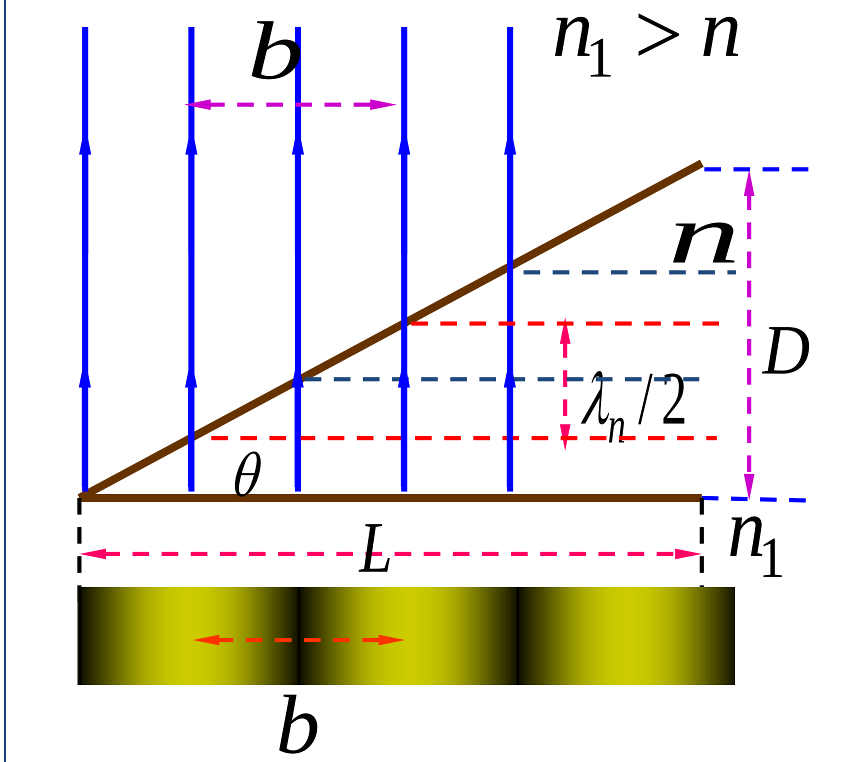
劈尖干涉

讨论

(1) 棱边处 $d=0$

$$\Delta = \frac{\lambda}{2}$$ 为暗纹.

$$d = \begin{cases} (k-\frac{1}{2})\frac{\lambda}{2n} & \text{（明纹）} \\ k\lambda/2n & \text{（暗纹）} \end{cases}$$



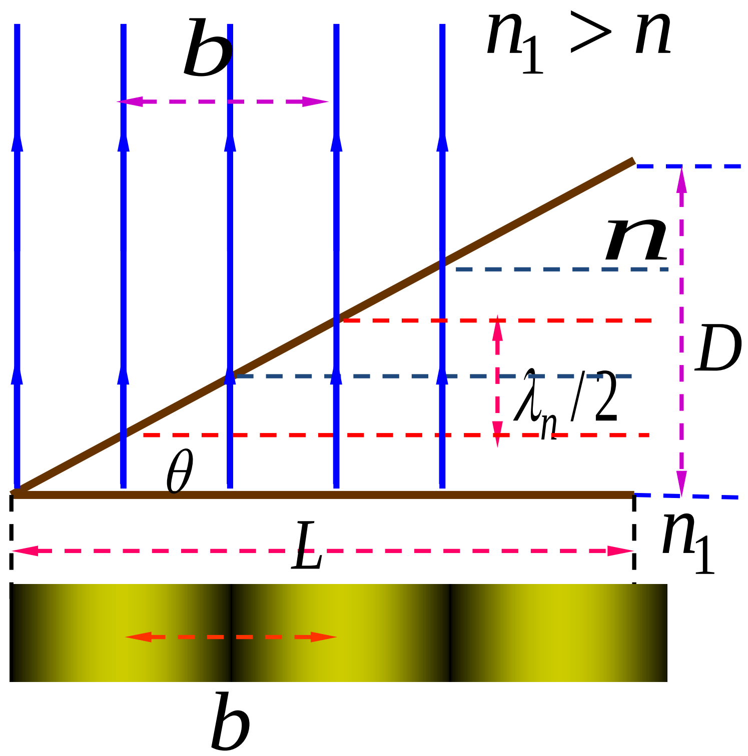
劈尖干涉

(2) 相邻明纹（暗纹）间的厚度差

$$d_{i+1} - d_i = \frac{\lambda}{2n} = \frac{\lambda_n}{2}$$

$$\theta \approx D/L$$

$$\theta \approx \frac{\lambda_n/2}{b}$$



劈尖干涉

(3) 条纹间距

$$b = \frac{\lambda}{2n\theta}$$

$$D = \frac{\lambda_n}{2b}L = \frac{\lambda}{2nb}L$$

例 1 波长为680 nm的平行光照射到L=12 cm长的两块玻璃片上，两玻璃片的一边相互接触，另一边被厚度D =0.048 mm的纸片隔开. 试问在这12 cm长度内会呈现多少条暗条纹？

解

$$2d+\frac{\lambda}{2}=(2k+1)\frac{\lambda}{2}$$

$$k=0,1,2,\cdots$$

$$2d+\frac{\lambda}{2}=(2k+1)\frac{\lambda}{2} \qquad k=0,1,2,\cdots$$

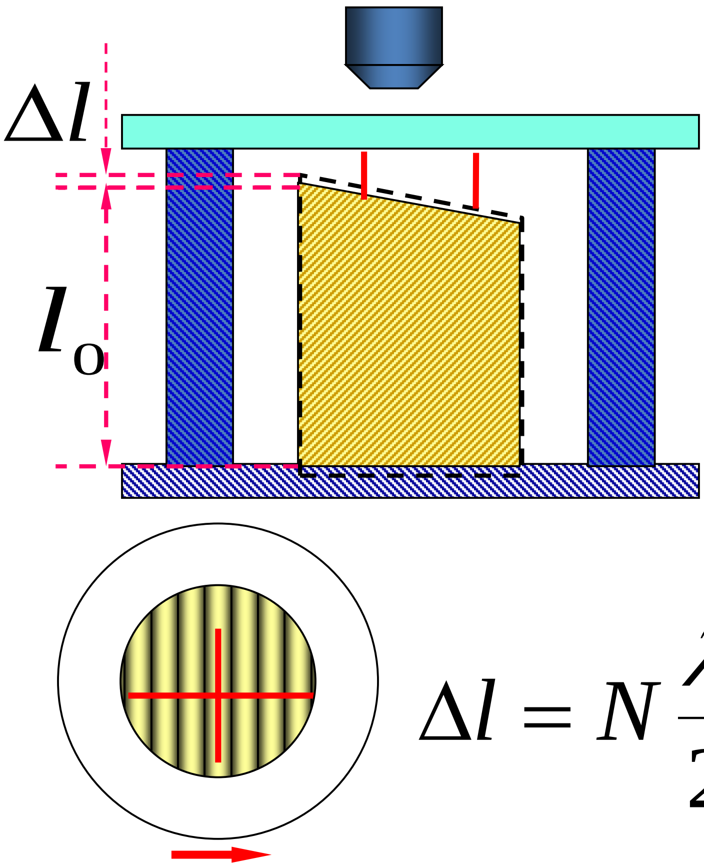
$$2D+\frac{\lambda}{2}=(2k_m+1)\frac{\lambda}{2}$$

$$k_m=\frac{2D}{\lambda}=141.2$$

共有142条暗纹

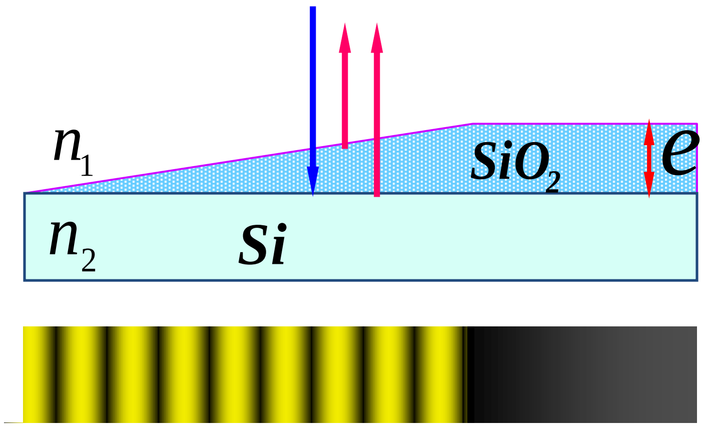
劈尖干涉的应用

(1) 干涉膨胀仪



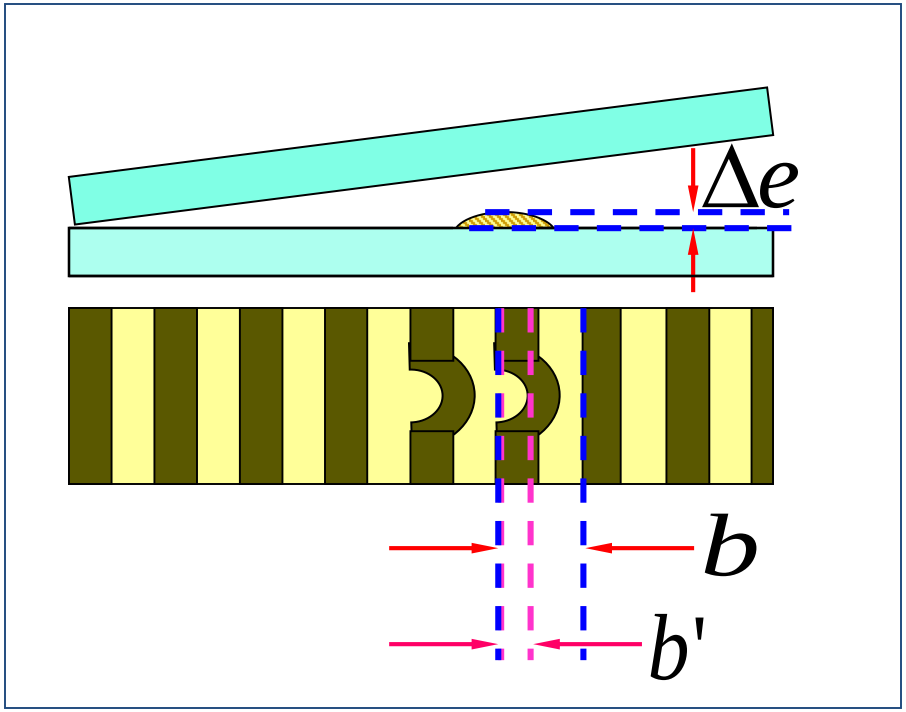
$$\Delta l = N\frac{\lambda}{2}$$

(2) 测膜厚



$$e = N\frac{\lambda}{2n_1}$$

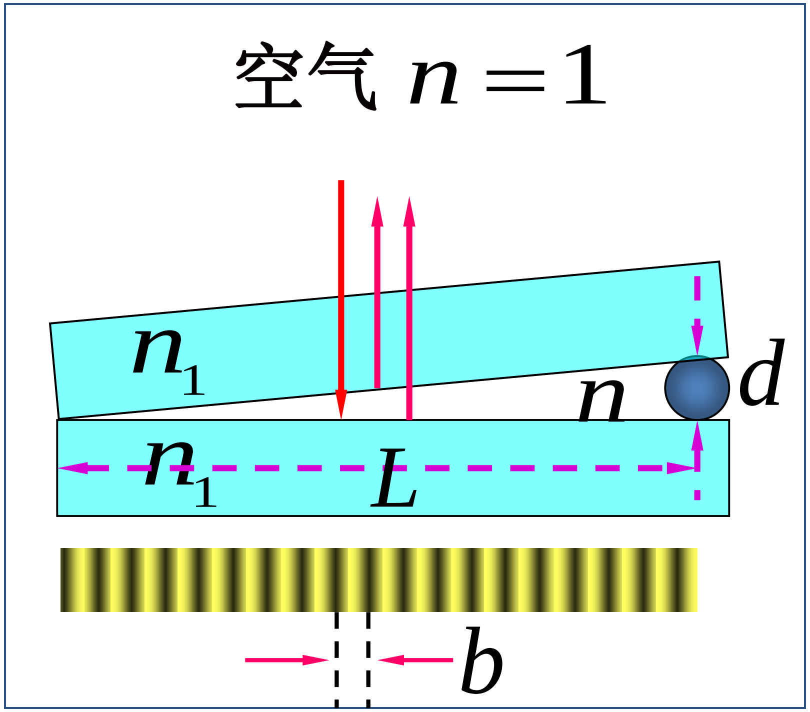
(3) 检验光学元件表面的平整度



$$\Delta e = \frac{b'}{b}\frac{\lambda}{2}$$

$$\approx \frac{1}{3}\cdot\frac{\lambda}{2} = \frac{\lambda}{6}$$

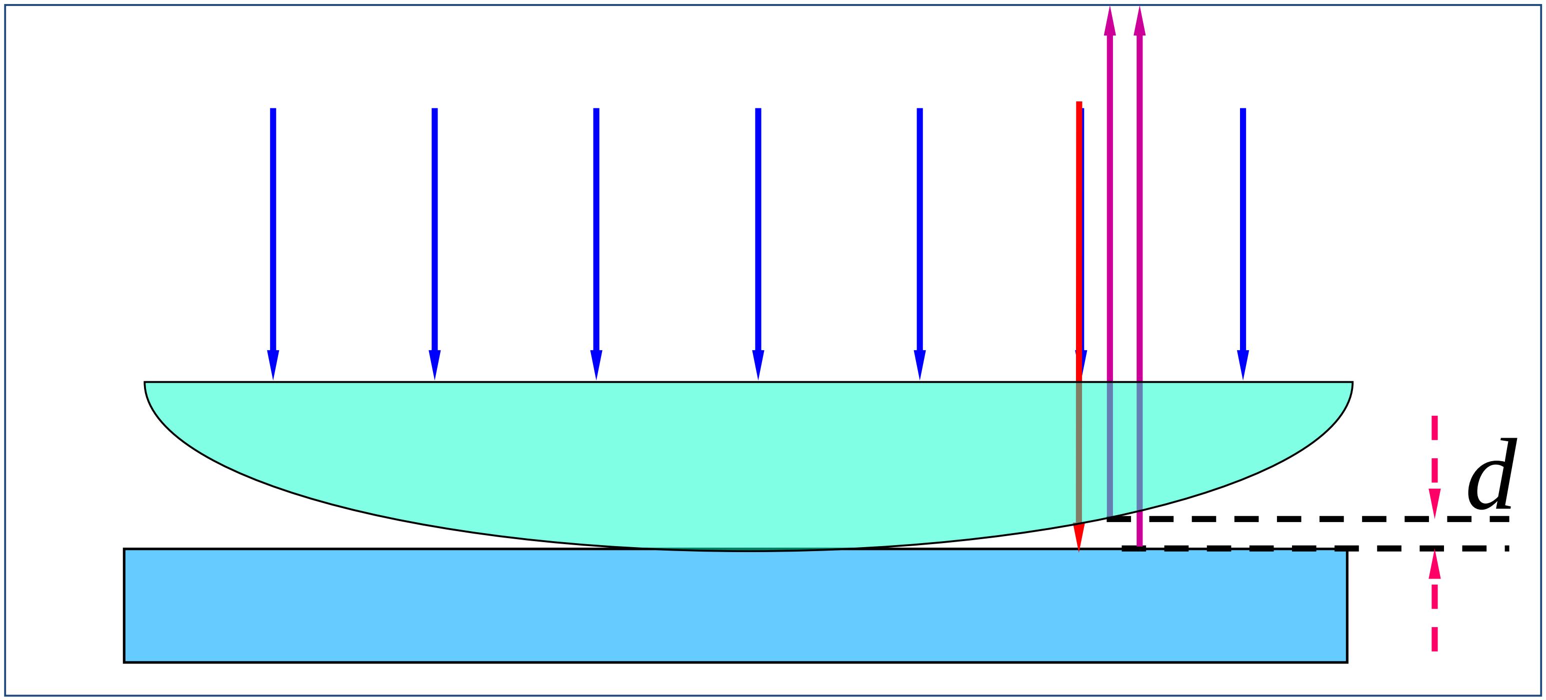
(4) 测细丝的直径



$$d = \frac{\lambda}{2n} \cdot \frac{L}{b}$$

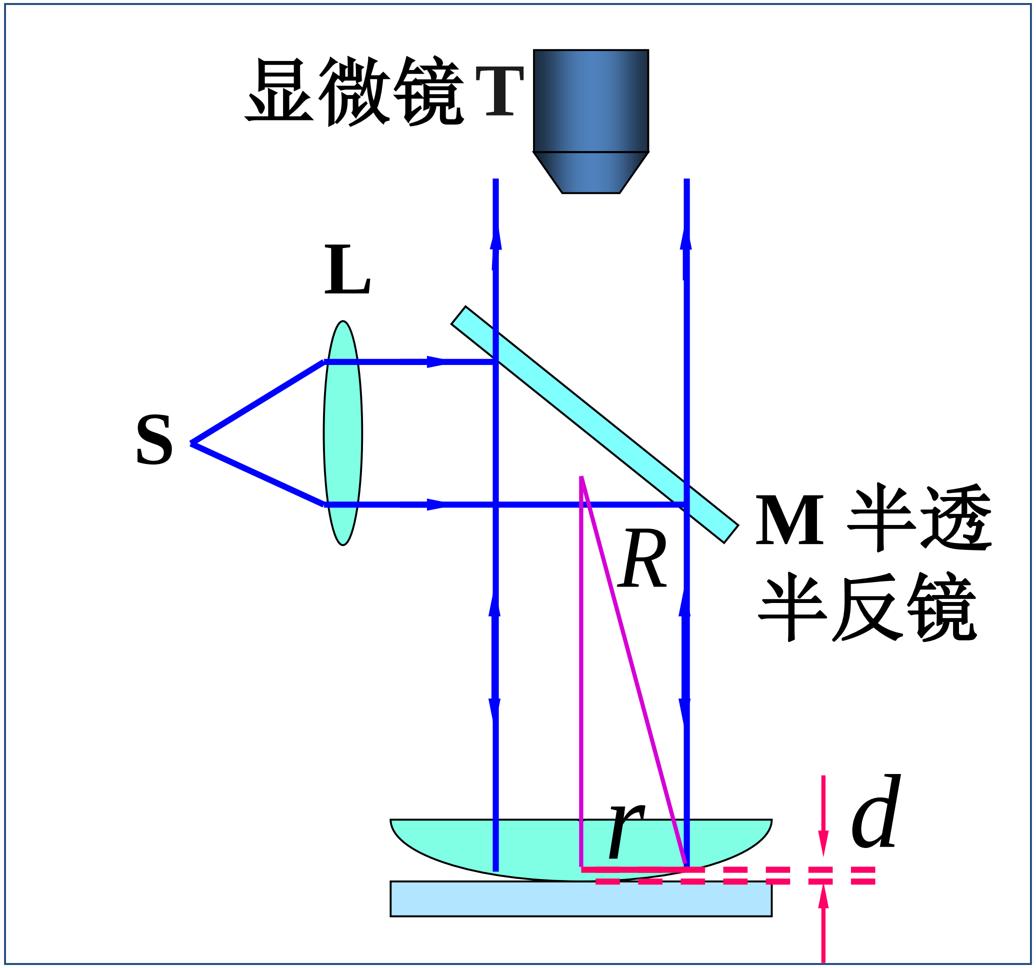
二 牛顿环

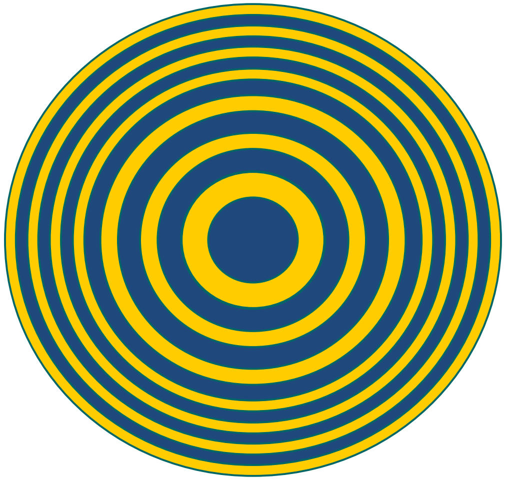
由一块平板玻璃和一平凸透镜组成



光程差 $\varDelta = 2d + \dfrac{\lambda}{2}$

牛顿环实验装置

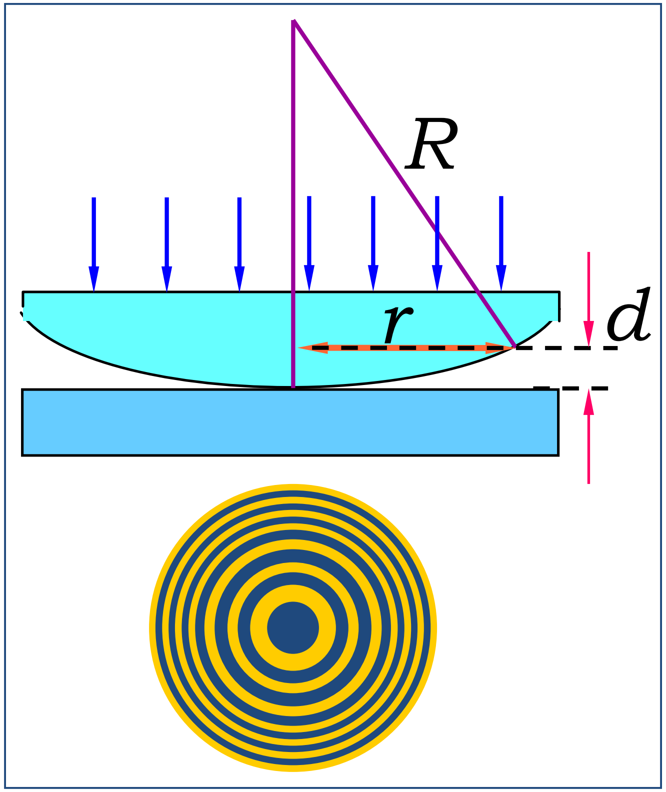




牛顿环干涉图样

光程差 $\Delta = 2d + \dfrac{\lambda}{2}$

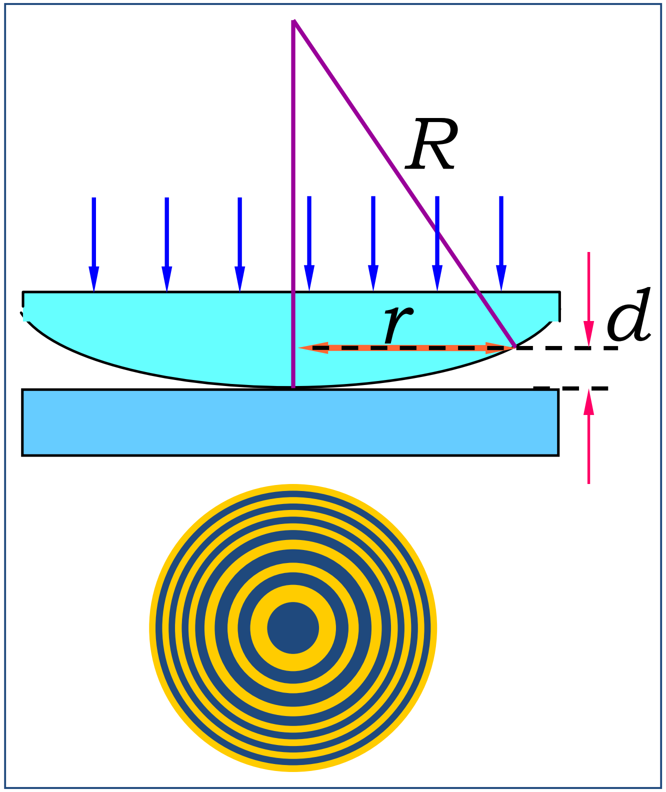
$$\Delta = \begin{cases} k\lambda \quad (k = 1,2,\cdots) & \text{明纹} \\ (k+\dfrac{1}{2})\lambda \quad (k = 0,1,\cdots) & \text{暗纹} \end{cases}$$



$$r^2 = R^2 - (R-d)^2 = 2dR - d^2$$

$$\because R >> d \quad \therefore d^2 \approx 0$$

$$r = \sqrt{2dR} = \sqrt{(\Delta - \frac{\lambda}{2})R}$$



$$\Rightarrow \begin{cases} r = \sqrt{(k - \frac{1}{2})R\lambda} & \text{明环半径} \\ r = \sqrt{kR\lambda} & \text{暗环半径} \end{cases}$$

讨论

明环半径 $r=\sqrt{(k-\frac{1}{2})R\lambda}$ $(k=1,2,3,\cdots)$

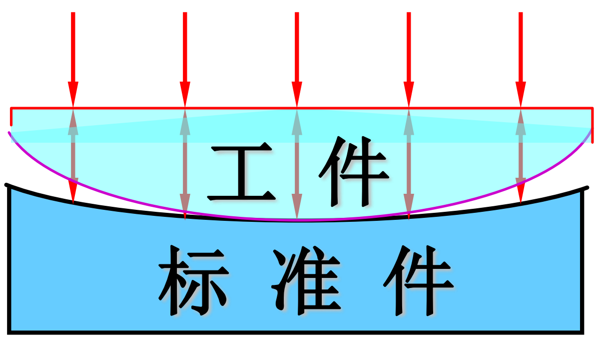
暗环半径 $r=\sqrt{kR\lambda}$ $(k=0,1,2,\cdots)$

(1) 从反射光中观测，中心点是暗点还是亮点？从透射光中观测，中心点是暗点还是亮点？

(2) 属于等厚干涉，条纹间距不等，为什么？

(3) 将牛顿环置于 $n>1$ 的液体中，条纹如何变？

(4) 应用例子：可以用来测量光波波长，用于检测透镜质量，曲率半径等.

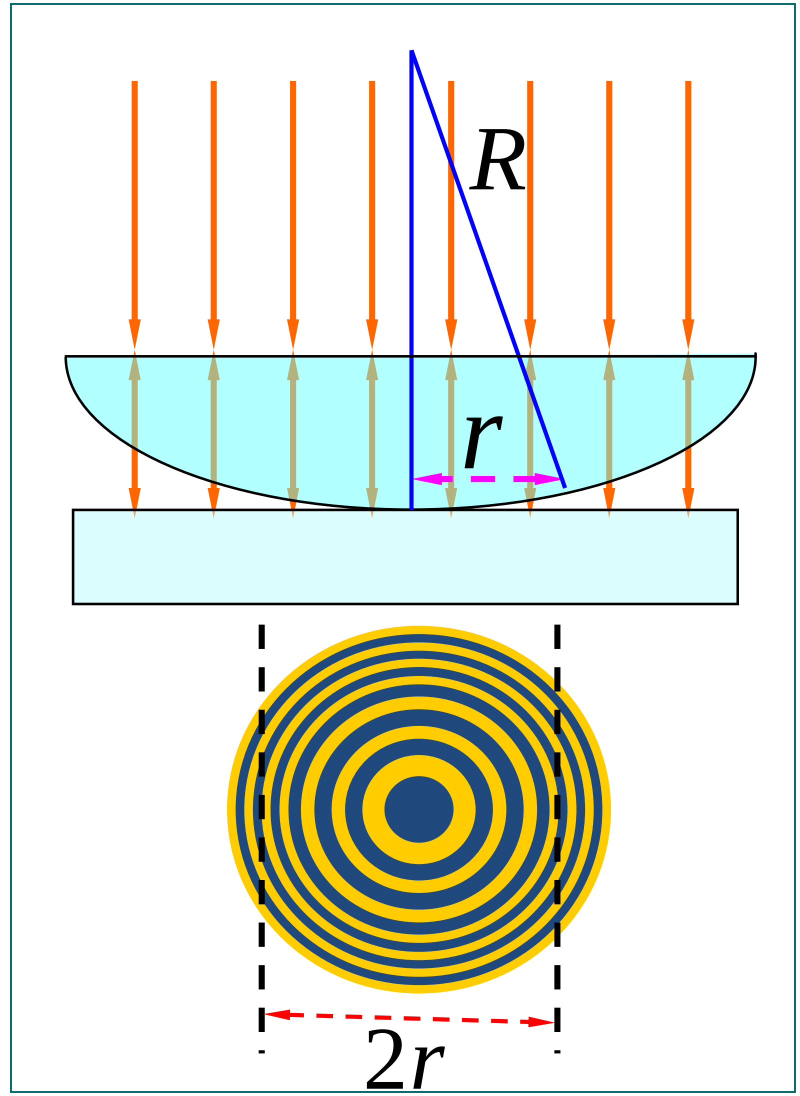


测量透镜的曲率半径

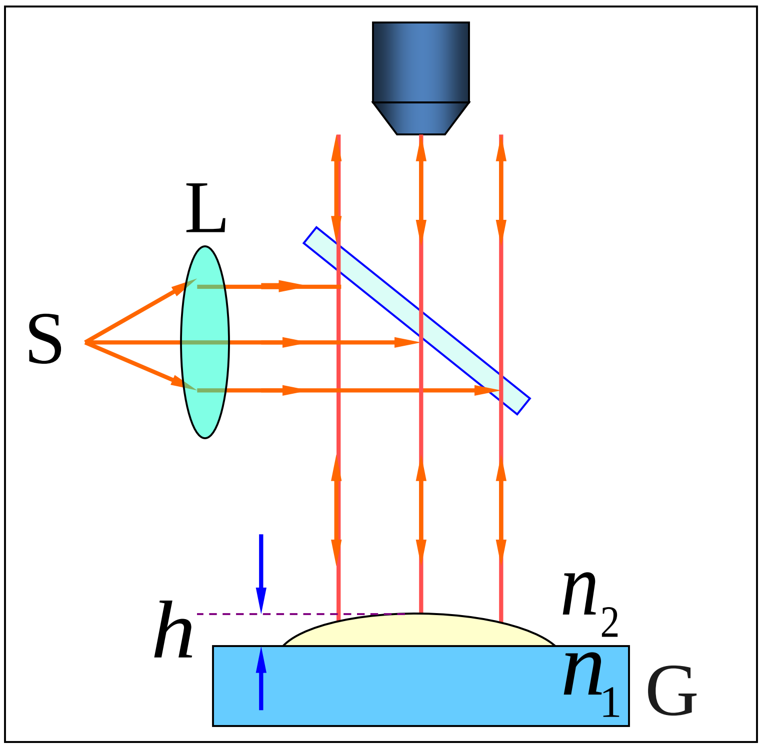
$$r_k^2 = kR\lambda$$

$$r_{k+m}^2 = (k+m)R\lambda$$

$$R = \frac{r_{k+m}^2 - r_k^2}{m\lambda}$$

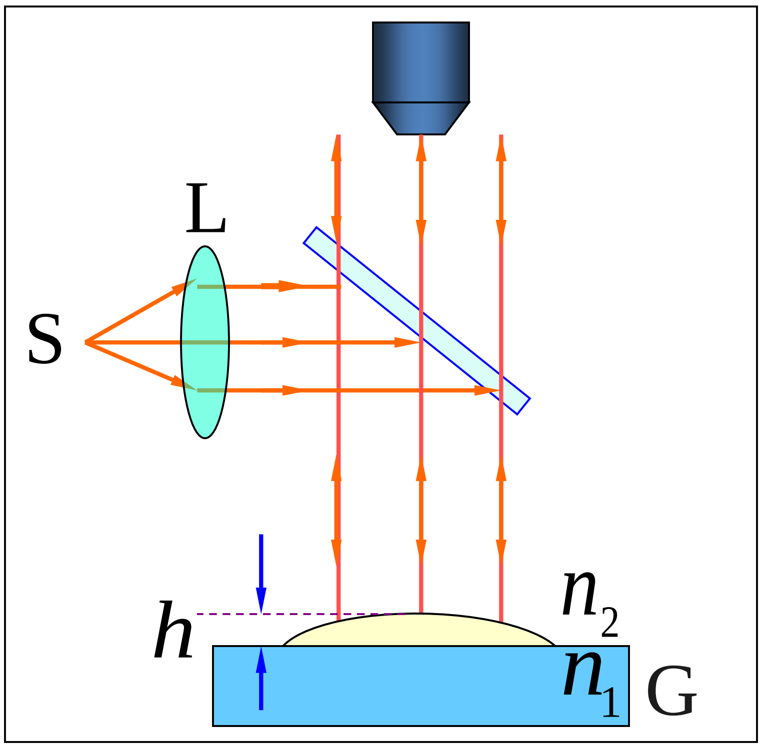


例2 如图所示为测量油膜折射率的实验装置，在平面玻璃片G上放一油滴，并展开成圆形油膜，在波长 $\lambda = 600\ \text{nm}$ 的单色光垂直入射



下，从反射光中可观察到油膜所形成的干涉条纹．已知玻璃的折射率为 $n_1 = 1.50$，油膜的折射率 $n_2 = 1.20$，问：当油膜中心最高点与玻璃

片的上表面相距 $h = 8.0\times10^{2}\,\mathrm{nm}$ 时，干涉条纹是如何分布的？可看到几条明纹？明纹所在处的油膜厚度为多少？

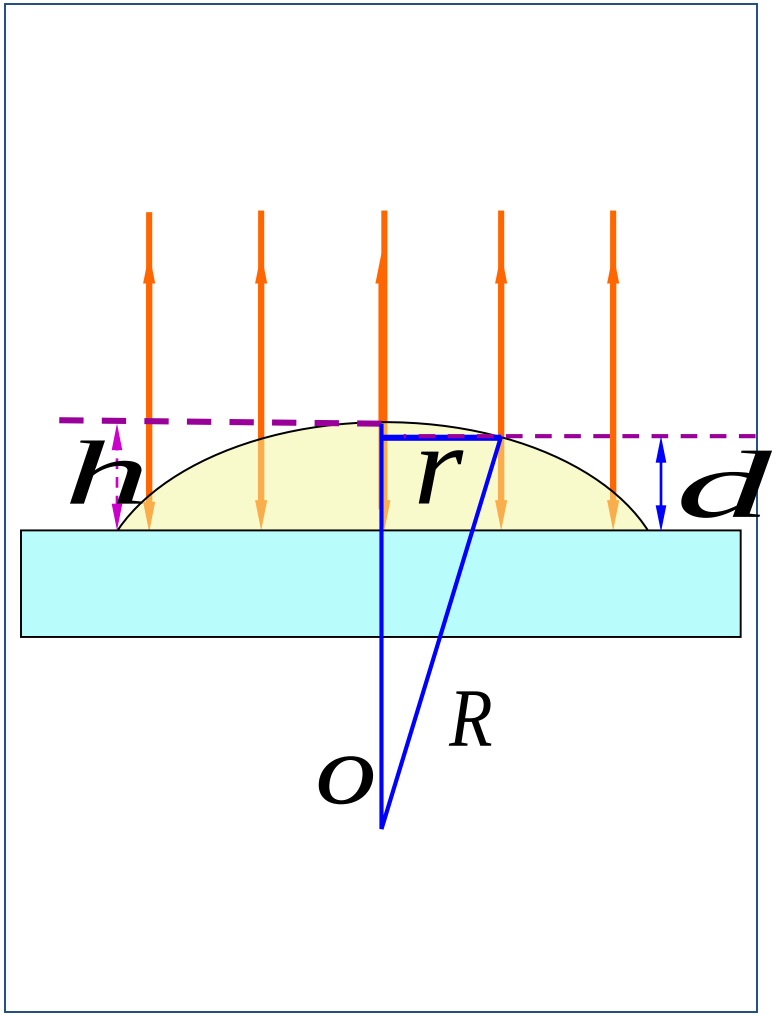


解 条纹为同心圆

$$\Delta = 2n_2 d_k = k\lambda \quad \text{明纹}$$

$$d_k = k\frac{\lambda}{2n_2}$$

$$k = 0,1,2,\cdots$$



油膜边缘 $k=0, d_0=0$

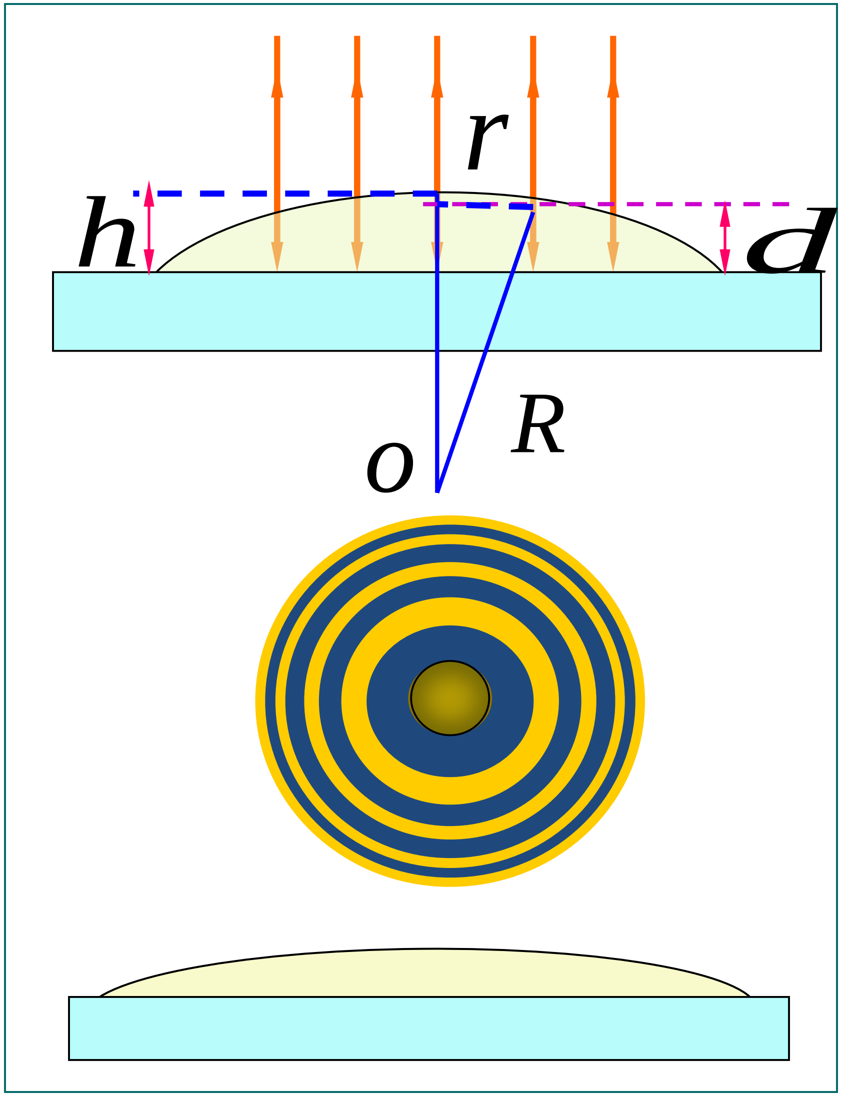
$k=1,\quad d_1=250\text{nm}$

$k=2,\quad d_2=500\text{nm}$

$k=3,\quad d_3=750\text{nm}$

$k=4,\quad d_4=1000\text{nm}$

由于 $h=8.0\times10^2\text{nm}$ 故可观察到四条明纹.



讨论

油滴展开时，条纹间距变大，条纹数减少

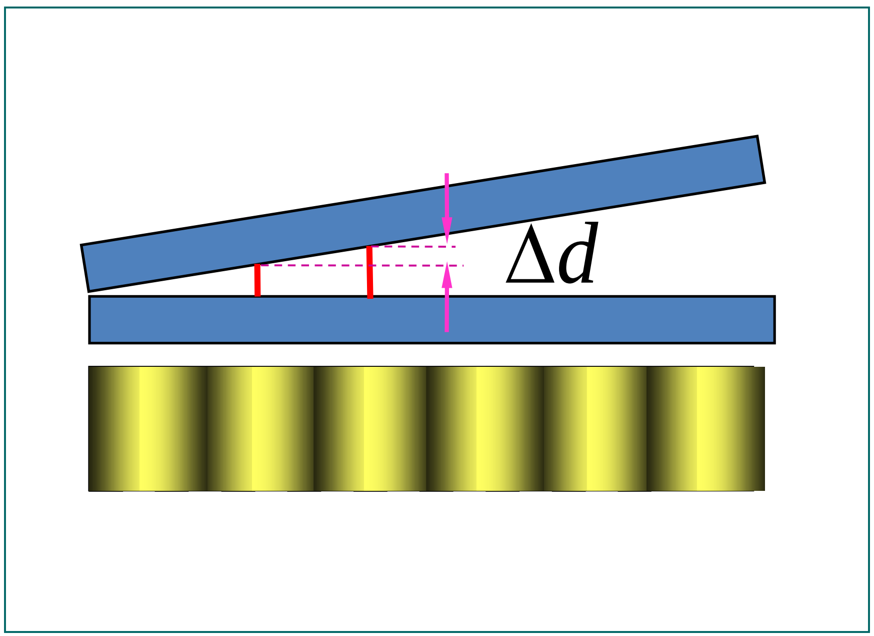
$$R^2 = r^2 + [R-(h-d)]^2$$

$$r^2 \approx 2R(h-d)$$

$$R \approx \frac{r^2}{2(h-d)}$$

总结

(1) 干涉条纹为光程差相同的点的轨迹，即厚度相等的点的轨迹.

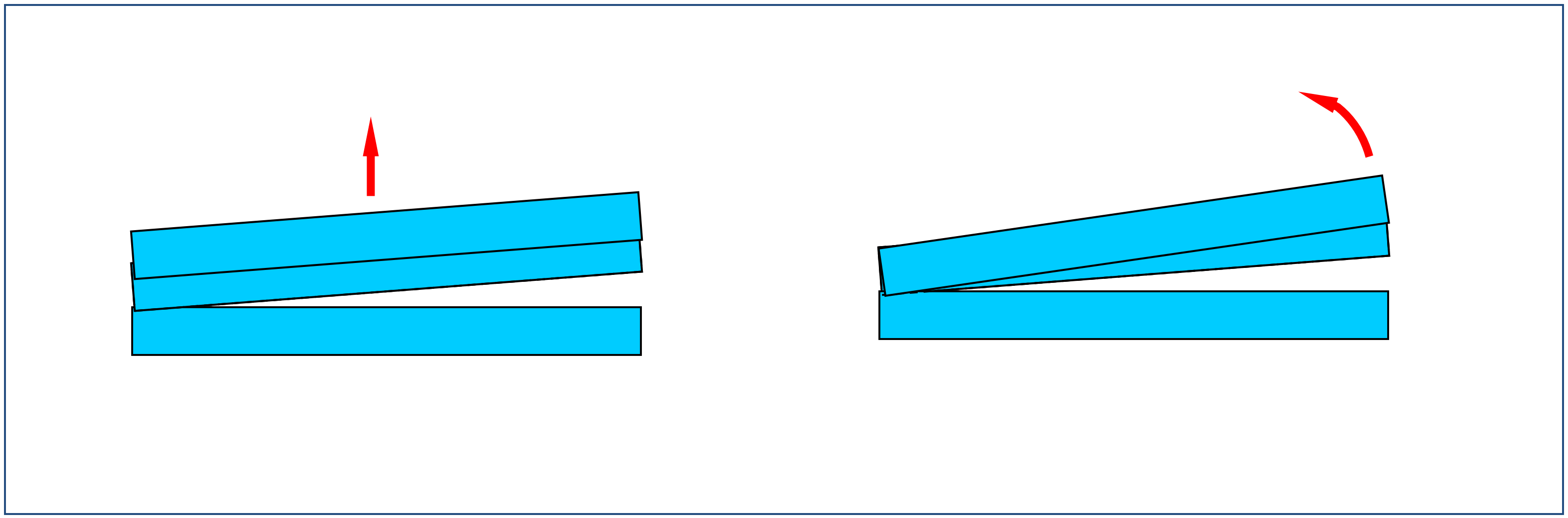


$$\Delta k = 1$$

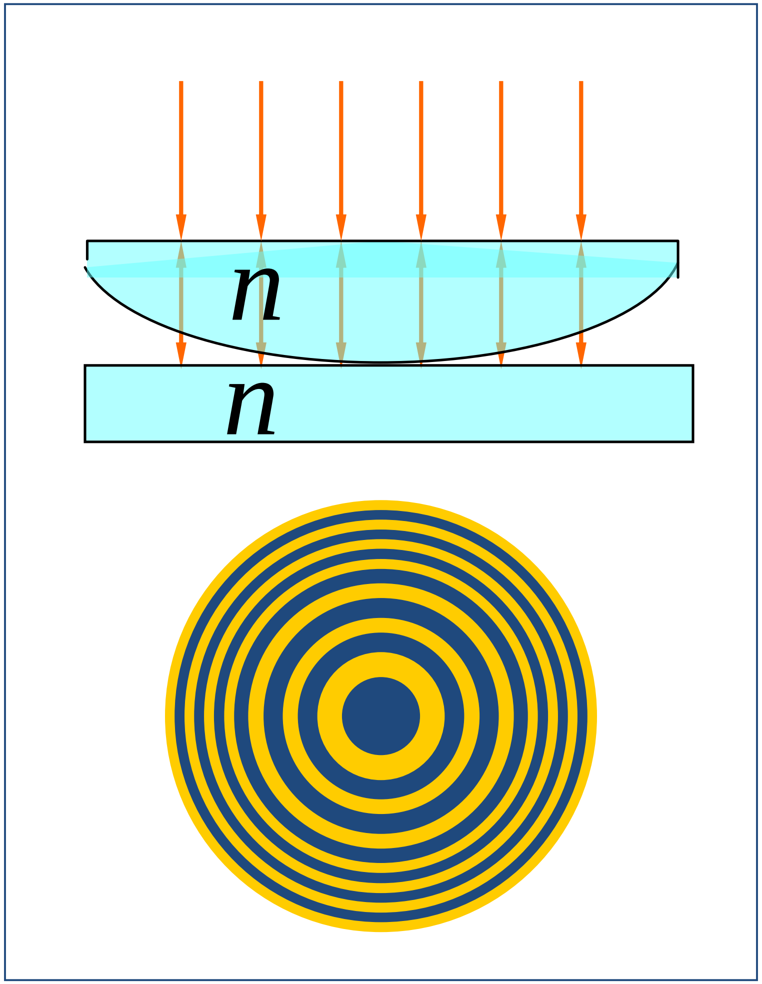
$$\Delta d = \frac{\lambda}{2n}$$

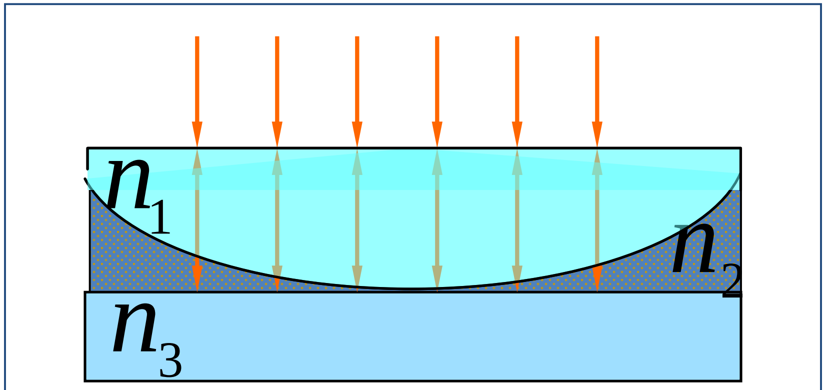
(2) 厚度线性增长条纹等间距，厚度非线性增长条纹不等间距.

(3) 条纹的动态变化分析（n, λ, θ 变化时）



(4) 半波损失需具体问题具体分析.





$$n_1 < n_2 < n_3$$